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Yellow nutsedge (Cyperus esculentus) Growth and Tuber Production in Response to Increasing Glyphosate Rates and Selected Adjuvants

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Abstract:	Greenhouse studies were conducted to evaluate the influence of selected adjuvants on glyphosate efficacy on yellow nutsedge and tuber production. Glyphosate was applied at 0, 0.25, 0.43, 0.87, 1.26 (1x rate), and 1.74 kg ae ha-1 31 d after yellow nutsedge was planted. Each rate was mixed with one of the following adjuvants: ammonium sulfate (AMS); or AMS plus NIS; or AMS plus an experimental adjuvant (W-7995) plus NIS. Plants were evaluated for visual injury and the number and size of tubers produced. Dose response curves based on log-logistic models were used to determine the effective glyphosate rate plus adjuvant that provided both 90% visual yellow nutsedge injury (ED90) and reduced tuber production. Addition of NIS to glyphosate plus AMS resulted in the greatest yellow nutsedge injury 28 DAT. Addition of the experimental adjuvant plus NIS resulted in similar injury as NIS alone. The ED90 for visual injury at 28 DAT was 2.12 kg ha-1 with glyphosate plus AMS and NIS compared to 2.18 kg ha-1 for W-7995 plus NIS and 3.06 kg ha-1 with AMS alone. The ED90 rates with different adjuvants represent 168%, 173%, and 243% of the highest glyphosate rate (1.26 kg ha-1) labeled for application on many glyphosate resistant crops. However, the estimated ED90 to reduce small, medium, large, and total tubers were 1.60, 1.50, 1.63, and 1.66 kg ha-1, respectively. The results suggest that increases in labeled rates of glyphosate may be required to reduce yellow nutsedge tuber production in field conditions. Use of lower glyphosate rates should be discouraged as it may increase tuber production and exacerbate yellow nutsedge expansion in infested fields.

Yellow nutsedge (*Cyperus esculentus*) Growth and Tuber Production in Response to Increasing Glyphosate Rates and Selected Adjuvants

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Greenhouse studies were conducted to evaluate the influence of selected adjuvants on glyphosate efficacy on yellow nutsedge and tuber production. Glyphosate was applied at 0, 0.25, 0.43, 0.87, 1.26 (1x rate), and 1.74 kg ae ha^{-1} 31 d after yellow nutsedge was planted. Each rate was mixed with one of the following adjuvants: ammonium sulfate (AMS); or AMS plus NIS; or AMS plus an experimental adjuvant (W-7995) plus NIS. Plants were evaluated for visual injury and the number and size of tubers produced. Dose response curves based on log-logistic models were used to determine the effective glyphosate rate plus adjuvant that provided both 90% visual yellow nutsedge injury (ED_{90}) and reduced tuber production. Addition of NIS to glyphosate plus AMS resulted in the greatest yellow nutsedge injury 28 DAT. Addition of the experimental adjuvant plus NIS resulted in similar injury as NIS alone. The ED_{90} for visual injury at 28 DAT was 2.12 kg ha^{-1} with glyphosate plus AMS and NIS compared to 2.18 kg ha^{-1} for W-7995 plus NIS and 3.06 kg ha^{-1} with AMS alone. The ED_{90} rates with different adjuvants represent 168%, 173%, and 243% of the highest glyphosate rate (1.26 kg ha^{-1}) labeled for

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application on many glyphosate resistant crops. However, the estimated ED_{90} to reduce small, medium, large, and total tubers were 1.60, 1.50, 1.63, and 1.66 kg ha^{-1}, respectively. The results suggest that increases in labeled rates of glyphosate may be required to reduce yellow nutsedge tuber production in field conditions. Use of lower glyphosate rates should be discouraged as it may increase tuber production and exacerbate yellow nutsedge expansion in infested fields.

Nomenclature: Glyphosate; yellow nutsedge, *Cyperus esculentus* L. CYPES.

Key words: adjuvants, yellow nutsedge tubers, furrow irrigated systems.

Yellow nutsedge is a perennial weed found throughout the world in many crop production systems (Anderson 1999; Holm et al. 1991; Schippers et al. 1995). It is naturalized within the United States (U.S.), where it was first reported in the northeastern states in 1889 (DeFelice 2002). Yellow nutsedge has since spread to nearly all crop producing regions of the U.S. The impact of yellow nutsedge on production agriculture has led to its listing as a prohibited noxious weed in 10 states (Anderson 1999). Hauser (1971) suggested that the increase of yellow nutsedge in agricultural fields is largely due to reduced competition from annual weeds, which tend to have effective control measures.

Populations of yellow nutsedge can expand and contract in individual fields based on a variety of environmental and management factors. However, given its perennial nature, yellow nutsedge remains a problem once it produces mature tubers in a field. Control of yellow nutsedge is difficult because reproduction is mainly by underground vegetative propagules (rhizomes and tubers), which persist for 3 to 5 yr (DeFelice 2002). Population dynamic models have indicated that farming operations were the main cause of yellow nutsedge dispersal in the fields (Schippers et al. 1993). Tillage caused a threefold increase in infestation expansion level compared to no-tillage. Tuber adherence to field machinery during physical weed management activities also play a significant role in horizontal yellow nutsedge distribution in infested fields (Schippers et al. 1993; Webster 2005).

Yellow nutsedge is an important weed problem of agricultural fields in the Treasure Valley of eastern Oregon and southwestern Idaho, mainly due to lack of effective control strategies in direct-seeded onion (*Allium cepa* L.) crops. Surveys conducted by Ransom et al. (2003) indicated dry bulb onion yield reductions averaged 42 percent in fields that were heavily infested with yellow nutsedge. Mechanical control through well-timed soil cultivation can be used to destroy yellow nutsedge plants before tuber formation, but it is not an option in the furrow irrigated fields after beds are formed. In the Treasure Valley, beds are designed to facilitate furrow irrigation and are formed during the fall preceding spring onion planting before yellow nutsedge emerges. Agricultural equipment used to create a uniform gradient and furrow irrigation beds possibly contributes to further distribution of yellow nutsedge in the fields. Onions are relatively short-statured plants with narrow, round, vertical leaves which produce an open canopy and are easily outcompeted by yellow nutsedge (J. Felix, personal observation). The openness of onion canopy allows yellow nutsedge to flourish under prevailing high air temperature conditions, which are often accompanied by high light intensity and constant soil moisture in the furrow irrigated fields. Onion management practices, including frequent irrigation and the high nitrogen fertilization required to maximize yield, also favor yellow nutsedge growth (Keeling et al. 1990). Additionally, the direct-seeded dry bulb onion based crop rotations in the Treasure Valley limit the use of most soil-applied or postemergence herbicides with efficacy on yellow nutsedge. For example, onions are sensitive to even low soil residues of halosulfuron-methyl, which persist after corn (*Zea mays* L.) harvest (J. Felix, personal observation).

Herbicides registered to control yellow nutsedge in direct-seeded dry bulb onions include *S*-metolachlor and dimethenamid-p, which are applied when seedlings are at the 2-leaf stage. However, by the time onions reach the 2-leaf stage, yellow nutsedge has already emerged, and both *S*-metolachlor and dimethenamid-p do not control emerged weeds (Anonymous 2008; Anonymous 2010a). Consequently, current efforts to control yellow nutsedge rely on the use of glyphosate applications in transgenic corn and sugar beets (*Beta vulgaris* L.) grown in rotation with onion.

Reported results for yellow nutsedge control with glyphosate have varied. Pratt et al. (2003) reported that adjuvants improved weed control with glyphosate, but none was superior to that achieved with the addition of ammonium sulfate (AMS). Adjuvants are defined as ‘‘any substance in a herbicide formulation or added to the spray tank to modify herbicidal activity or application characteristics’’ (Ahrens 1994). Adjuvants counteract antagonisms with solution components that reduce herbicide activity. They also help to improve herbicide movement across the cuticle. Yellow nutsedge has a thick waxy cuticle on the adaxial leaf surface (Schippers et al. 1995), which may present a barrier for herbicide absorption under hot conditions (Dayan et al. 1996). The relatively high amount of epicuticular wax on yellow nutsedge leaves may be responsible for a low absorption rate of herbicides in the absence of adjuvants (Dayan et al. (1996). Nelson et al. (2002) suggested that addition of adjuvants to glyphosate may increase yellow nutsedge control under hot, dry conditions. Ammonium sulfate increased glyphosate phytotoxicity (Nalewaja and Matysiak 1993; Thelen et al. 1995) and improved weed control, especially when used with alkaline water as a carrier. Recently however, Webster et al. (2008) reported reduction of yellow nutsedge tuber production with a single glyphosate application in greenhouse conditions without the use of adjuvants. Nelson et al. (2002) reported little glyphosate efficacy on yellow nutsedge when applied with adjuvants, and Ethridge and Mueller (1998) found that sequential applications were required to provide effective yellow nutsedge control.

Control of yellow nutsedge is also reported to be affected by glyphosate rate and application timing. Stoller et al. (1975) reported poor control of yellow nutsedge with glyphosate rates below 2.2 kg ha^{-1}. Several reports suggest that glyphosate application rate and the plant age at the time of application influence yellow nutsedge control and viable tuber production (Appleby and Paller 1978; Keeley et al. 1985; Pereira and Crabtree 1986; Stoller et al. 1975). However, differences in yellow nutsedge biotype response to glyphosate should not be discounted (Holt 1994).

The adoption of glyphosate resistant crops (GRC) in the Treasure Valley, including corn, sugar beets (*Beta vulgaris* L.) and alfalfa (*medicago sativa* L.), enables growers to apply glyphosate directly to these crops during the growing season. Improved glyphosate efficacy when used in these crops could reduce yellow nutsedge tuber production in years preceding direct-seeded onions in the Treasure Valley. Glyphosate labels recommend addition of surfactants only when the carrier volume is above 280 L ha^{-1} and glyphosate rates are below 0.6 kg ha^{-1} (Anonymous 2010b), but anecdotal evidence indicates that addition of nonionic surfactants may improve yellow nutsedge control even at low spray volumes. Currently, most onion growers in the Treasure Valley apply a mixture of glyphosate plus AMS at rates ranging from 0.6 to 1.26 kg ha^{-1} to manage yellow nutsedge in GRC. The objective of this greenhouse study was to compare the effect of glyphosate applied in mixture with an experimental adjuvant, W-7995, and a non-ionic surfactant to glyphosate plus AMS on yellow nutsedge visual injury and tuber production.

Materials and Methods

Greenhouse Experiments. Yellow nutsedge tubers were collected from a field in Malheur County, Oregon (N 43° 59.615, W -117° 00.404) in October 2008 and 2009, placed in plastic bags and stored at 4 C until used in the experiments. Greenhouse studies were conducted in February 2009 and 2010 at Corvallis, Oregon. Pots were filled with greenhouse commercial potting mix[1], watered and left on greenhouse benches to equilibrate to room conditions. An experimental unit consisted of a circular 35 cm deep by 29 cm diam pot. Tubers were positioned between two pieces of wet germination paper and placed in a plastic tray filled with sterile sand to 2.5 cm depth and wetted to capacity. The trays were placed in a germination chamber set at 24/20 C with 14/10 h of light/dark and the tubers were monitored daily for germination. After 9 d, tubers with a 2 mm bud protrusion were removed from the tray and one tuber planted in each pot in the greenhouse at a depth of 2 to 3 cm. The greenhouse had natural light supplemented with metal halide lamps, with average day/night temperatures of 24/20 C and light duration of 14/10 h light/dark. The experiment was a complete randomized design with three replications and was repeated. Pots were systematically rotated on the benches within each replication to avoid shade and positional effects in the greenhouse. Pots were watered twice per week and each was fertilized during the first 4 weeks with 40 ml of 9.875 g L^{-1} solution of 16-16-16 (NPK) fertilizer[2].

Isopropopylamine salt of glyphosate[3] was applied 31 d after nutsedge tubers were transplanted, when the average plant height was 57 cm. The list of treatments including adjuvant combinations are presented in Table 1. Spray products were mixed in the following order prior to application: 1) half of the required amount of water; 2) AMS; 3) glyphosate; 4) W-7995[4]; 5) NIS and then the remaining water. Treatments were applied using a spray chamber[5] equipped with a single TeeJet 8003 EVS nozzle[6] calibrated to deliver 112 L ha^{-1} at 221 kPa.

Yellow nutsedge visual injury ratings relative to the nontreated control were performed at 21 and 28 d after treatment (DAT). Evaluations were based on a 0 to 100% scale, where 0% represented no injury and 100% complete plant death. Plants were harvested after the last evaluation by clipping the aboveground biomass and tubers separated from the roots by washing over sieves. Tubers were quantified based on diameter and divided into extra small (≤ 0.254 cm), small (0.254 to 0.508 cm), medium (0.508 to 0.76 cm), and large (≥ 0.76 cm) sizes using stacked sieves. All tubers were air dried for 6 h, cold conditioned for 7 d at 4 C, and planted in 10 cm pots containing commercial potting mix to assess their viability. Germination of the tubers was quantified 3 wk after planting based on tuber bud sprout and protrusion. Tubers with any evidence of bud protrusion were considered to have germinated.

Statistical Analysis. The data from visual evaluations of yellow nutsedge injury and number of tubers were subjected to a normality test before ANOVA. Because transforming the data did not change the results of analysis, the actual values are presented. Data were pooled over study when there was no significant study-by-treatment interaction and tested for heterogeneity of variance. ANOVA was performed using PROC MIXED in SAS[7] (1999) to assess the effect of study, glyphosate rate, adjuvant combination, and their interactions on the visual yellow nutsedge plant injury response and the number and size of tubers produced ($P \leq 0.05$). Regression of yellow nutsedge plant injury ratings over herbicide rate was performed using a four-parameter log-logistic model as described by Seefeldt et al. (1995) and indicated below:

$$Y = C + (D - C)/\{1 + \exp\,[B(\log X - \log E)]\} \qquad [1]$$

where Y is the response (e.g., percent of yellow nutsedge injury), *C* is the lower limit, *D* is the upper limit, *B* is the slope of the line, *X* is the herbicide rate, and *E* is the rate resulting in a 50% response (e.g., 50% injury, which is also known as effective dose 50 (ED_{50}, also called I_{50}). Analysis of the dose-response curves and ED_{90} values was completed using the statistical software, R 2.7.2[8], and the *drc* package as described by Knezevic et al. (2007). When the data did not fit the model (lack of convergence), only ANOVA was performed and the means were compared using Fisher’s protected LSD ($P \leq 0.05$).

Results and Discussion

Visual Injury. There were no significant differences between study or glyphosate rate-by-study interactions for any of the variables; therefore, the data were pooled over study and analyzed for glyphosate rate and adjuvant effects. Visual evaluations at 21 DAT were similar to ratings at 28 DAT; therefore, only evaluations at 28 DAT are presented. Injury symptoms on yellow nutsedge were characterized by leaf chlorosis followed by necrosis of the tissue. Differences in yellow nutsedge visual injury at 28 DAT were due to glyphosate rate and adjuvant selection (Figure 1). At low glyphosate rates (<0.5 kg ha^{-1}), the addition of AMS and NIS resulted in greater visual injury. Addition of the experimental adjuvant (W-7995) plus AMS and NIS or NIS alone performed similarly at higher glyphosate rates (≥ 0.87 kg ha^{-1}). The ED_{50} glyphosate rate for yellow nutsedge injury at 28 DAT was 0.79 kg ha^{-1} when W-7995 plus NIS were added to the spray solution (Table 2). The corresponding rate to elicit 50% injury when AMS and NIS were added was 0.54 kg ha^{-1} compared to 0.82 kg ha^{-1} for glyphosate plus AMS alone. It is not clear why the experimental adjuvant performed similar to AMS alone even with the inclusion of NIS. These results suggest that growers in eastern Oregon could benefit from the addition of NIS to the mixture of glyphosate plus AMS to control weeds in GRC, especially when targeting yellow nutsedge. Also, the use of glyphosate at rates ≤ 0.87 kg ha^{-1} to control yellow nutsedge should be discouraged. Estimates for ED_{90} for visual injury at 28 DAT ranged from 3.06 kg ha^{-1} with AMS alone to 2.12 kg ha^{-1} with the addition of NIS. These results partly corroborate findings by Stoller et al. (1975) who reported poor control of yellow nutsedge with glyphosate rates below 2.2 kg ha^{-1}. Our results suggest that the addition of NIS in the glyphosate plus AMS mixture may enhance yellow nutsedge injury. With the commercialization of GRC, growers are able to apply glyphosate directly to GRC preceding onion production, yet yellow nutsedge infestations continue to expand in the furrow irrigated systems of eastern Oregon. Unpublished information indicates that growers in the Treasure Valley apply glyphosate at rates ranging from 0.473 to 0.946 kg ha^{-1} (J. Felix, personal observation). It is possible that the use of lower glyphosate rates may be partly contributing to the expansion of yellow nutsedge in the area through the production of small and medium size tubers (Figure 2).

Yellow Nutsedge Tuber Production. Tubers were produced at all glyphosate rates applied. There has been anecdotal indication that yellow nutsedge plants sprayed with glyphosate tend to produce smaller tubers. Most of the tubers in this study were either small (0.25 to 0.51 cm) or medium (0.51 to 0.76 cm) size in diameter, but extra small (≤0.25 cm) and large (>0.76 cm) were also produced (Figure 2). Differences in the number of tubers for each category were only influenced by glyphosate rate; therefore, the data were combined over adjuvants for analysis.

Total number of Tubers. The total number of tubers produced was greater when glyphosate was applied at 0.25 and 0.43 kg ha^{-1} relative to the nontreated control (Figure 2). A similar number of tubers were produced in the nontreated control and when glyphosate was applied at ≤ 0.87 kg ha^{-1}. The lowest number of tubers was produced when glyphosate was applied at rates ≥ 1.26 kg ha^{-1}. The ED_{50} and ED_{90} were estimated to be 1.03 kg ha^{-1} and 1.66 kg ha^{-1}, respectively (Table 2). The ED_{90} for total tubers (1.66 kg ha^{-1}) was lower than that estimated to elicit 90% visual injury to yellow nutsedge at 28 DAT (2.12 kg ha^{-1}). These results suggest that, ultimately, yellow nutsedge visual injury may not be a good predictor of tuber production.

Extra Small Tubers. There was no difference among glyphosate rates for the number of extra small tubers produced relative to the nontreated control, which ranged from 0 to 4 tubers pot^{-1} (data not shown). Production of extra small tubers in particular is troublesome for land managers of the furrow irrigated fields of the Treasure Valley because this size may possibly increase tuber buoyancy and contribute to the dissemination through irrigation water movement in canals and ditches, especially during the initial irrigation event when the soil is still loose from tillage. Even though the water is filtered at entry points into different farms, extra small tubers may enter the fields in case of an overflow due to accumulation of plant debris at water filtration points, which is very common.

Small Size Tubers. The greatest number of small size tubers relative to the nontreated control was produced when glyphosate was applied at the rate of 0.43 kg ha^{-1} (Figure 2). The ED_{50} rate for small size tubers reduction was 0.95 kg ha^{-1} and the ED_{90} glyphosate rate was estimated to be 1.60 kg ha^{-1} (Table 2).

Medium Size Tubers. Medium size tubers comprised the largest proportion of the total tubers produced (Figure 2). Yellow nutsedge plants treated with glyphosate at 0.25 and 0.43 kg ha^{-1} produced the greatest medium size tubers, which was similar to the nontreated control. The fewest medium size tubers were produced when glyphosate was applied at 1.26 kg ha^{-1} or greater (Figure 2). The ED_{50} and ED_{90} for the medium size tubers were estimated to be 0.78 kg ha^{-1} and 1.50 kg ha^{-1}, respectively (Table 2).

Large Size Tubers. Yellow nutsedge plants produced relatively few large tubers compared to small and medium size tubers (Figure 2). The fewest large tubers relative to the nontreated control were produced when glyphosate was applied at rates ≥ 1.26 kg ha^{-1}. Plants treated with the lowest glyphosate rate (0.25 kg ha^{-1}) produced 1.6 times the number of large tubers compared to the nontreated control. The ED_{50} rate for the large tubers was 0.86 kg ha^{-1}, while the estimated glyphosate rate to provide 90% reduction of large size tubers was 1.63 kg ha^{-1} (Table 2).

Visual injury provides an insight into vegetative plant effects resulting from glyphosate application, but long-term yellow nutsedge management is dependent on inhibiting tuber production. The results from these studies indicated that glyphosate rate determines the number and size of yellow nutsedge tubers produced. Tuber production in yellow nutsedge is a result of plant response to excess carbohydrates and is regulated by the availability of growth substances (Bhowmik 1997). Yellow nutsedge, as with all plants, must have sufficient leaf area for photosynthesis to occur and produce sufficient carbohydrates in the form of photoassimilates (Hopkins 1995). Therefore, reducing healthy leaf tissue could decrease the amount of carbohydrate, thus reducing tuber population. At low application rates, there is the least leaf tissue injury and the plant initiates tuber production as a survival mechanism. Because the level of assimilates is limited due to tissue injury, many small and medium size tubers are produced at low glyphosate rates. As the glyphosate rate increases, the leaf tissue injury increases and yellow nutsedge can not generate enough assimilates to sustain many tubers, hence the limited tuber production at glyphosate rates of 1.26 kg ha^{-1} or greater. Our results suggest that the use of glyphosate at rates lower than 0.87 kg ha^{-1} to control yellow nutsedge should be discouraged. Furthermore, the continued prevalence of glyphosate resistant weeds in the US necessitates the use of different strategies including herbicides with soil residual to manage yellow nutsedge instead of total glyphosate weed control programs.

Yellow Nutsedge Tuber Germination. Germination of 7 d cold conditioned tubers varied by size and was only affected by glyphosate rates (Figure 3). In general, the greatest tuber germination was observed for tubers produced when glyphosate was applied at rates ≤ 0.43 kg ha^{-1}. Germination of small and medium size tubers ranged from 0 to 45% and 0 to 36%, respectively (Figure 3A and B). Large size tubers had the lowest germination, which ranged from 0 to 27% (Figure 3C). The combined total germination ranged from 0 to 34% (Figure 3D). Germination of extra small tubers for the nontreated, glyphosate applied at 0.25, 0.43, 0.87, 1.26, and 1.74 kg ha^{-1} was 10, 4, 22, 11, 6, and 0%, respectively (data not shown). It is unclear, but likely, that most of the tubers that did not germinate were viable but still dormant as a result of the short cold conditioning period. These results suggest that application of glyphosate at rates ≥ 1.26 kg ha^{-1} may possibly reduce tuber production. Field studies are needed to validate these results under furrow irrigated conditions.

The above results further demonstrated that the addition of the experimental adjuvant W-7995 plus NIS to glyphosate plus AMS spray mixture did not improve yellow nutsedge visual injury at 28 DAT. The addition of AMS and NIS improved visual injury but did not influence tuber production. Nelson et al. (2002) reported that addition of NIS, methylated seed oil, or crop oil concentrate to glyphosate plus diammonium sulfate did not increase yellow nutsedge control in the greenhouse or field. Our results show that visual injury increased with the addition of NIS, but reduction in the number of produced tubers was only attributed to the glyphosate rate used. These results corroborate the findings by Webster (2008) that glyphosate will reduce tuber production. Furthermore, the use of lower glyphosate rates produced greater number of tubers and should be discouraged in order to avoid increases in the number of yellow nutsedge tubers in individual fields. The estimated glyphosate rates to reduce small, medium, large, and total tubers were 1.60, 1.50, 1.63, and 1.66 kg ha^{-1}, respectively, and are slightly greater than the current highest single application rate recommended on the label (1.26 kg ha^{-1}) and used by growers on GRC. The use of lower glyphosate rates to manage yellow nutsedge should be discouraged as it may result in the production of small size tubers and further contribute to the distribution of yellow nutsedge in the furrow irrigated systems in the Treasure Valley of eastern Oregon. Finally, it should be emphasized that growers and weed managers need to practice a diversified yellow nutsedge control program in light of the increasing prevalence of glyphosate-resistant weed species in the US. Use of soil residual herbicides followed by glyphosate POST might be better than sequential application of glyphosate POST alone.

Sources of Materials

[1] Sunshine Mix #1, Sun Gro Horticulture Inc., 15831 N.E. 8th Street, Suite 100, Bellevue, WA 95008.

[2] Osmocote fertilizer, Scotts-Sierra Horticultural Products Company, 14111 Scottslawn Road, Marysville, OH 43041.

[3] Roundup PowerMax®, Monsanto Company, 800 Lindbergh Blvd., St. Louis, MO 63167.

[4] W-7995, Wilbur-Ellis, P. O. BOX 16458, Fresno, CA 93755.

[5] Spray chamber, DeVries Manufacturing, 28081 870th Ave, Hollandale, MN 56045.

[6] TeeJet 8003 EVS flat-fan nozzle tips, Spraying Systems Co., P.O. Box 7900, Wheaton, IL 60188.

[7] SAS user's guide. Version 9.2. Statistical Analysis Systems Institute, Inc., P.O. Box 8000, Cary, NC 25712-8000.

[8] R statistical software, R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org.

Literature Cited

Ahrens, W. H. 1994. Herbicide Handbook, 7th ed. Champaign, IL: Weed Science Society of America. pp. 310–318.

Anderson, W. P. 1999. Purple nutsedge (*Cyperus rotundus*) and yellow nutsedge (*Cyperus esculentus*). *In* Perennial Weeds. Ames, IA: Iowa State University Press. pp. 57–66.

Anonymous. 2008. Outlook® label. BASF Corporation, 26 Davis Drive, Research Park Triangle, NC 27709.

Anonymous. 2010a. Dual Magnum® label. Syngenta Crop Protection, Inc. P. O. BOX 18300, Greensboro, NC 27419.

Anonymous. 2010b. Roundup PowerMax® label 6302714-10. Monsanto Company, St. Louis, MO 63167.

Appleby, A. P. and E. C. Paller. 1978. Effect of naptalam on growth of yellow nutsedge and subsequent control with glyphosate. Weed Res. 18:247–253.

Bhowmik, P. C. 1997. Weed biology: importance to weed management. Weed Sci. 45:349–356.

Dayan, F. E., H. M. Green, J. D. Weete, and H. G. Hancock. 1996. Postemergence activity of sulfentrazone: effects of surfactants and leaf surfaces. Weed Sci. 44:797–803.

DeFelice, M. S. 2002. Yellow nutsedge (*Cyperus esculentus* L.): snack food of the gods. Weed Technol. 16:901-907.

Ethridge, R. E. and T. C. Mueller. 1998. Roundup Ultra effects on perennial weeds. Proc. South. Weed Sci. Soc. 51:10.

Hauser, E. W. 1971. Nutsedge: a worldwide plague. Weeds Today 2:21–23.

Holm, L. G., D. L. Plucknett, J. V. Pancho, and J. P. Herberger. 1991. The World’s Worst Weeds: Distribution and Biology. Malabar, FL: Krieger Publishing. Pp. 125–133.

Holt, J. S. 1994. Genetic variation in life history traits in yellow nutsedge (*Cyperus esculentus*) from California. Weed Sci. 42:378-384.

Hopkins, W. G. 1995. Introduction to Plant Physiology. New York: J. Wiley. 464 p.

Keeling, J. W., D. A. Bender, and J. R. Abernathy. 1990. Yellow nutsedge (*Cyperus esculentus*) management in transplanted onions (*Allium cepa*). Weed Technol. 4:68-70.

Keeley, P. E., C. H. Carter, and R. J. Thullen. 1985. Influence of glyphosate on resprouting of parent tubers of *Cyperus esculentus*. Weed Sci. 34:25–29.

Knezevic, S. Z., J. C. Streibig, and C. Ritz. 2007. Utilizing R software package for dose–response studies: the concept and data analysis. Weed Technol. 21:840–848.

Nalewaja, J. D. and R. Matysiak. 1993. Influence of diammonium sulfate and other salts on glyphosate phytotoxicity. Pest. Sci. 38:77-84.

Nelson, A. K., K. A. Renner, and D. Penner. 2002. Yellow nutsedge (*Cyperus esculentus*) control and tuber yield with glyphosate and glufosinate. Weed Technol. 16:360–365.

Pereira, W. and G. Crabtree. 1986. Absorption, translocation, and toxicity of glyphosate and oxyfluorfen in yellow nutsedge (*Cyperus esculentus*). Weed Sci. 34:923–929.

Pratt, D., J. J. Kells, and D. Penner. 2003. Substitutes for ammonium sulfate as additives with glyphosate and glufosinate. Weed Technol. Weed Technol. 17:576-581.

Ransom, C. V., C. A. Rice, and J. K. Ishida. 2003. Yellow nutsedge competition in dry bulb onion production. Oregon State University Agricultural Experiment Station Special Report 1055:97-99.

Schippers, P., S. J. T. Borg, J. M. Van Groenendael, and B. Habekotte. 1993. What makes *Cyperus esculentus* (yellow nutsedge) an invasive species? A spatial model approach. Proceedings Brighton Crop Protection Conference –Weeds 495-504.

Schippers, P., S. J. T. Borg, and J. J. Bos. 1995. A revision of the infraspecific taxonomy of *Cyperus esculentus* (yellow nutsedge) with an experimentally evaluated character set. Syst. Bot. 20:461–481.

Seefeldt, S. S., J. E. Jensen, and E. P. Fuerst. 1995. Log-logistic analysis of herbicide dose–response relationships. Weed Technol. 9:218–227.

Stoller, E. W., L. M. Wax, and R. L. Matthiesen. 1975. Response of yellow nutsedge and soybeans to bentazon, glyphosate, and perfluidone. Weed Sci. 23:215–221.

Thelen, K. D. E. P. Jackson, and D. Penner. 1995. The basis for the hard water antagonism of glyphosate activity. Weed Sci. 43:541-548.

Webster, T. M. 2005. Mulch type affects growth and tuber production of yellow nutsedge (*Cyperus esculentus*) and purple nutsedge (*Cyperus rotundus*). Weed Sci. 53:834–838.

Webster, T. M., T. L. Grey, J. W. Davis, and A. S. Culpepper. 2008. Glyphosate hinders purple nutsedge (*Cyperus rotundus*) and yellow nutsedge (*Cyperus esculentus*) tuber production. Weed Sci. 56:735-742.

Table 1. Treatments used in the greenhouse studies conducted at Corvallis, OR 2009 and 2010.

		Adjuvants		
Treatment	Rate (kg ae ha^{-1})	AMS[a] alone	+ NIS[a] + W-7995[b]	+ NIS
		% V/V		
Glyphosate	0	0.5		
Glyphosate	0	0.5	0.25 + 0.26	
Glyphosate	0	0.5		0.25
Glyphosate	0.25	0.5		
Glyphosate	0.25	0.5	0.25 + 0.26	
Glyphosate	0.25	0.5		0.25
Glyphosate	0.43	0.5		
Glyphosate	0.43	0.5	0.25 + 0.26	
Glyphosate	0.43	0.5		0.25
Glyphosate	0.87	0.5		
Glyphosate	0.87	0.5	0.25 + 0.26	
Glyphosate	0.87	0.5		0.25
Glyphosate	1.26	0.5		
Glyphosate	1.26	0.5	0.25 + 0.26	
Glyphosate	1.26	0.5		0.25
Glyphosate	1.74	0.5		
Glyphosate	1.74	0.5	0.25 + 0.26	
Glyphosate	1.74	0.5		0.25

[a] Abbreviations: AMS, ammonium sulfate; NIS=non ionic surfactant.

[b] W-7995is an experimental adjuvant intended to be used in conjunction with NIS.

Table 2. Regression parameter estimates and glyphosate rate (kg ae ha^{-1}) and adjuvants required to provide 90% yellow nutsedge control (ED_{90} (±SE)) based on visual ratings at 28 d after treatment and tuber production.[a]

Variable	Adjuvants	Regression parameters[b] (± SE)				ED_{90} (± SE)
		B	*C*	*D*	I_{50}	
Injury 28 DAT	AMS alone	-1.67 (0.44)	0.001 (8.7)	110.2 (56.8)	0.82 (0.16)	3.06 (0.89)
	W-7995+NIS	-2.16 (0.51)	0.001 (7.3)	79.8 (11.1)	0.79 (0.11)	2.18 (0.50)
	NIS	-1.60 (0.37)	0.001 (8.6)	108.6 (43.3)	0.54 (0.10)	2.12 (0.62)
Small tubers	Combined[c]	4.22 (1.98)	0.002 (5.79)	23.4 (2.2)	0.95 (0.09)	1.60 (0.27)
Medium tubers	Combined	3.35 (1.20)	0.001 (8.09)	32.3 (3.2)	0.78 (0.10)	1.50 (0.35)
Large tubers	Combined	3.39 (3.73)	0.255 (2.78)	5.9 (1.2)	0.86 (0.44)	1.63 (1.59)
Total tubers	Combined	4.63 (2.54)	-1.118 (17.35)	60.2 (4.8)	1.03 (0.22)	1.66 (0.71)

[a] Abbreviations: AMS, ammonium sulfate; DAT, days after treatment; NIS, nonionic surfactant.

[b]Parameters: *B*, slope of line; *C*, lower limit; *D*, is the upper limit; I_{50}, the glyphosate rate needed to cause a 50% visual injury; ED_{90}, is the glyphosate rate needed to cause 90% foliar injury or tuber reduction. Values in the brackets represent ± one standard error.

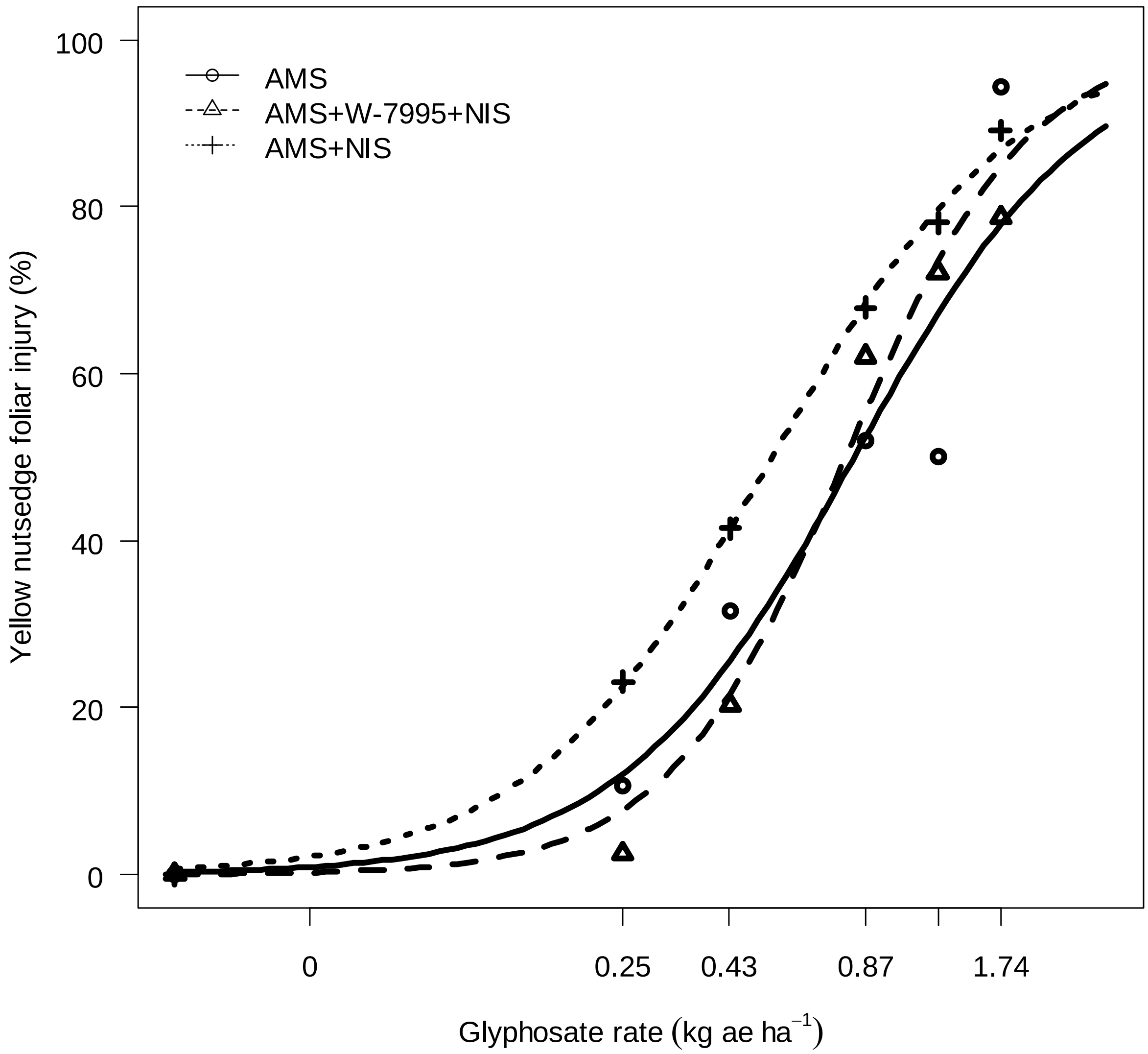
[c] The data were pooled across adjuvants within each category and fit to a nonlinear model (equation 1) after ANOVA indicated no difference among adjuvants.

Figure Legends

Figure 1. Regression lines (Equation 1) were fit to combined yellow nutsedge percent foliar visual injury 28 d after treatment. Data points represent average (replication and years) injury. Regression parameters estimates for glyphosate rates required to provide 50% and 90% injury are presented in Table 2. Values on the x-axis are in log scale.

Figure 2. Yellow nutsedge tubers produced in response to increasing glyphosate rate in greenhouse studies, 2009-2010, Corvallis, OR. The number of small yellow nutsedge tubers (0.254 to 0.508 cm); medium size (5.08 to 7.6 mm); large size (≥ 7.6 mm); and the total number of tubers pot^{-1} produced were combined across adjuvants and studies. The regression lines are plotted using Equation 1, and parameter values for the glyphosate rates required to obtain 50% and 90% tuber reduction are presented in Table 2. Values on the x-axis are in log scale.

Figure 3. Percent germination of yellow nutsedge tubers from plants treated with variable glyphosate rates in the greenhouse, 2009 to 2010, Corvallis, OR. Small tubers had a diameter of 0.254 to 0.508 cm (3A); medium size were 5.08 to 7.6 mm (3B); large size were ≥ 7.6 mm (3C); and total tuber numbers produced pot^{-1} (3D) were combined across adjuvants and studies. Vertical line represents LSD ($P \leq 0.05$).



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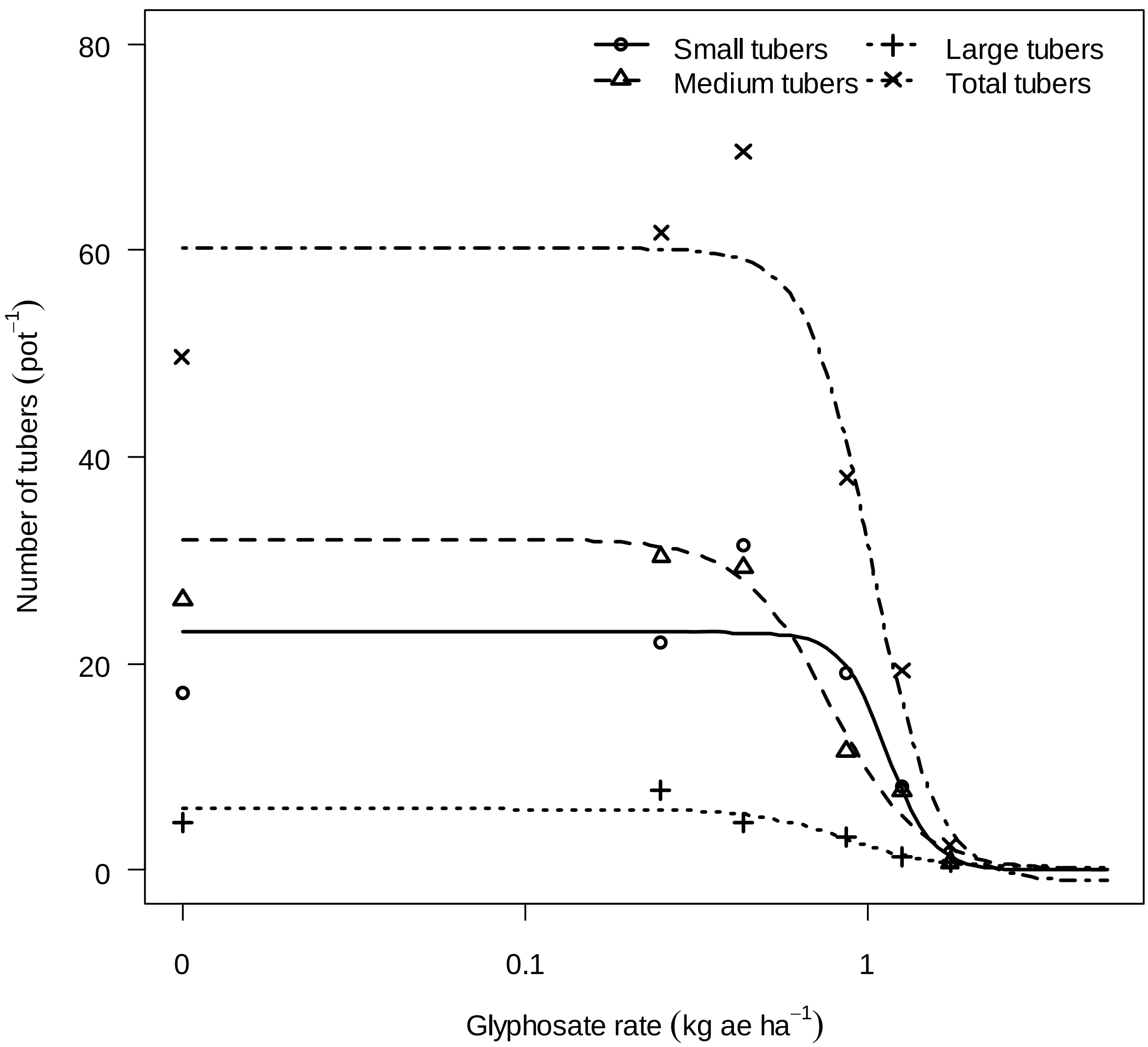
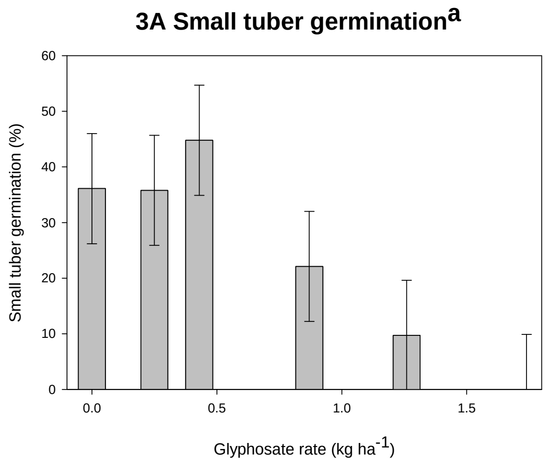
362 Figure 1.

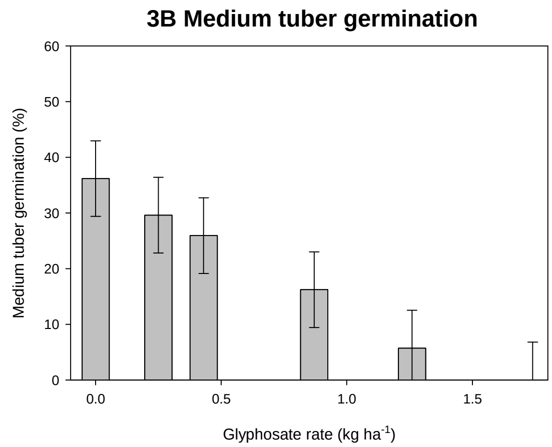


Small tubers
Medium tubers
Large tubers
Total tubers
80
60
40
20
0
Number of tubers (pot^{-1})
0
0.1
1
Glyphosate rate (kg ae ha^{-1})

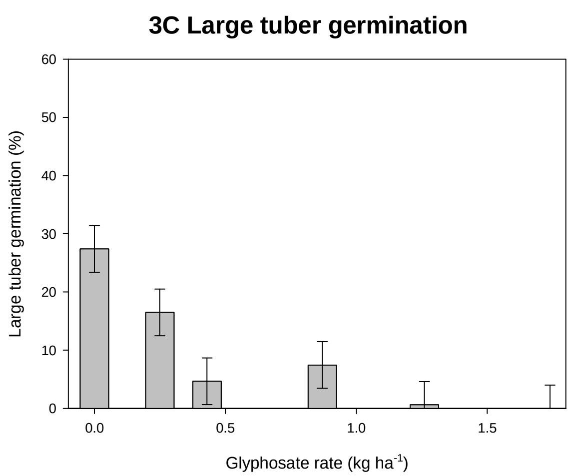
Figure 2



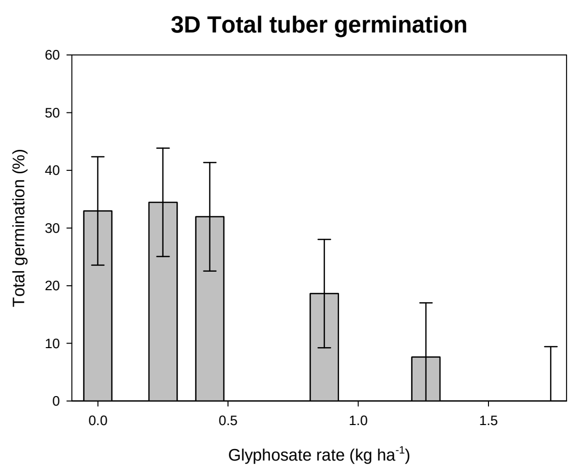
[a]Harvested number of small tubers pot^{-1} was 17, 22, 31, 19, 8, and 0 for the untreated, glyphosate at 0.25-, 0.43-, 0.87-, 1.26-, and 1.74 kg ha^{-1}, respectively.



Harvested number of medium tubers pot^{-1} was 26, 30, 29, 12, 8, and 1 for the untreated, glyphosate at 0.25-, 0.43-, 0.87-, 1.26-, and 1.74 kg ha^{-1}, respectively.



Number of large tubers pot^{-1} harvested was 5, 8, 5, 3, 1, and 1 for the untreated, glyphosate at 0.25-, 0.43-, 0.87-, 1.26-, and 1.74 kg ha^{-1}, respectively.



Harvested total number of tubers pot^{-1} was 50, 62, 70, 38, 19, and 3 for the untreated, glyphosate at 0.25-, 0.43-, 0.87-, 1.26-, and 1.74 kg ha^{-1}, respectively.

Figure 3.

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